CHAPTER- 5
Studies on carbonyl-ene reactions of fluoroketones
Studies on carbonyl-ene reaction with hexafluoroacetone trihydrate (HFAT) and 1,1,1-trifluoromethyl pyruvate, these results are discussed part A and part B as given below.

**Part A: Carbonyl-ene reaction of hexafluoroacetone trihydrate (HFAT)**

**Introduction**

Hexafluoroisopropanol (HFIP) functionality is a very strong hydrogen bond donor, and molecules appended with this group often exhibit interesting properties. For example, hexafluoroisopropanol functionalized siloxane polymers, such as SXFA, found applications in micro electromechanical system (MEMS)-based chemical sensors for detection of noxious chemicals such as explosives and nerve gas agents, chemical preconcentrators for micro analytical detection techniques and analytical and purification applications. Several HFIP functionalized compounds are also useful as chemical amplification resists for 157 nm lithography, and also as pharmaceuticals.

![Chemical structure of SXFA](image)

One of the general methods for the preparation of hexafluoroisopropanol (HFIP) functionalized derivatives is the carbonyl-ene reaction of anhydrous hexafluoroacetone (AHFA) with an alkene having allylic hydrogens. However, this method has the following drawbacks: AHFA is a highly toxic gas (bp -26 °C) and is expensive and special equipment is required for handling. With AHFA, yields are often very low and form a mixture of products as shown in Scheme 1. Because of these disadvantages with AHFA, studies for development of a more simple and convenient alternative approach for this reaction is desired.
Hexafluoroacetone trihydrate (HFAT) is a widely available and inexpensive chemical. Since HFAT is a liquid (bp 106–108 °C) at room temperature, it is highly convenient for handling and storage. However, unlike AHFA, HFAT is highly unreactive with alkenes and its carbonyl-ene reactions are not known in literature. Hence, we developed a new method for application of HFAT in carbonyl-ene reaction.

**Present Work**

In our study, we found porous solids such as molecular sieves, silica gel or alumina to catalyse carbonyl-ene reaction with HFAT when heated with an alkene at 100 °C producing HFIP functionalized derivatives in high yields. We found this reaction to proceed more efficiently under microwave heating conditions. The typical results observed with α-methyl styrene, which was reacted with HFAT in the presence of 3Å molecular sieves under thermal and microwave conditions are shown in Scheme 2.

**Scheme 1**

**Scheme 2: A study of carbonyl-ene reaction using HFAT**
AHFA is a strong electrophile and the mechanism of its carbonyl-ene reaction was known to involve a four-member, cyclic dipolar addition transition state. HFAT is, however, not a strong electrophile and the mechanism of its carbonyl-ene reaction is not clear. In a control experiment, no AHFA was generated when HFAT was heated with molecular sieves. This shows that the involvement of AHFA in the formation of observed products in the present study is a remote possibility.

The carbonyl-ene reaction of HFAT with α-methyl styrene was studied with a variety of solids such as molecular sieves (3Å, 4Å and 5Å MS), silica gel, alumina, calcium oxide and montmorillonite K10 clay and also with water-tolerant Lewis acid catalysts, namely, La(OTf)₃, Eu(OTf)₃, Gd(OTf)₃ and Yb(OTf)₃, under microwave heating (800W, 100 °C, 10 min). In this study, molecular sieves (3Å, 4Å and 5Å MS) and silica gel were found to be highly promising in promoting the reaction and alumina was found to be moderately active. The order of efficiency of these solids in catalyzing the carbonyl-ene reaction is 3Å MS > 4Å MS > 5Å MS > silica gel > alumina. Calcium oxide was found to be ineffective in catalyzing the reaction.

With K10 clay and lanthanide triflates, oligomers of α-methylstyrene are essentially formed in the reaction. The representative results are shown in Table 1.
In our further study, we have investigated the carbonyl-ene reactions of HFAT with a variety of alkenes 1a-h under microwave irradiation (800W, 100 °C, 10 min) and also under conventional heating in an oil bath at 100 °C. In this study, the microwave-assisted reactions were found to proceed very rapidly (in 10 min) giving the HFIP functionalized derivatives 2a-h in 62–97% yields. On the other hand, the reactions under conventional heating also gave the products in comparable yields (56–95%), but the reaction times were comparatively very long (>24 h). The results obtained in this study are presented in Table 2.
Table 2: Carbonyl-ene reactions of hexafluoroacetone trihydrate with alkenes

<table>
<thead>
<tr>
<th>Entry</th>
<th>Alkene 1</th>
<th>Adduct 2</th>
<th>Conventional heating</th>
<th>Microwave heating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>%Yield&lt;sup&gt;a&lt;/sup&gt; (time, h)</td>
<td>%Yield&lt;sup&gt;a&lt;/sup&gt;, (time, min)</td>
</tr>
<tr>
<td>a</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td>95(24)</td>
<td>97(10)</td>
</tr>
<tr>
<td>b</td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
<td>82(24)</td>
<td>93(10)</td>
</tr>
<tr>
<td>c</td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
<td>78(24)</td>
<td>92(10)</td>
</tr>
<tr>
<td>d</td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
<td>56(28)</td>
<td>62(10)</td>
</tr>
<tr>
<td>e</td>
<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
<td>63(28)</td>
<td>94(10)</td>
</tr>
<tr>
<td>f</td>
<td><img src="image11.png" alt="Image" /></td>
<td><img src="image12.png" alt="Image" /></td>
<td>64(28)</td>
<td>85(10)</td>
</tr>
<tr>
<td>g</td>
<td><img src="image13.png" alt="Image" /></td>
<td><img src="image14.png" alt="Image" /></td>
<td>73(28)</td>
<td>89(10)</td>
</tr>
<tr>
<td>h</td>
<td><img src="image15.png" alt="Image" /></td>
<td><img src="image16.png" alt="Image" /></td>
<td>60(28)</td>
<td>67(10)</td>
</tr>
</tbody>
</table>

<sup>a</sup>Isolated yields. All products were characterized by IR, <sup>1</sup>H & <sup>13</sup>C NMR and Mass spectral data.
As an illustrative example, the characterization of 2d based on its spectral data is as follows: In IR spectrum (Fig.5.1) of 2d, we observed characteristic absorption bands at 3540 cm\(^{-1}\), which corresponds to OH functionality. In \(^1\)H NMR spectrum (Fig.5.2) of 2d, we observed a multiplet at 7.19 ppm integrating for five protons, which corresponds to aromatic protons. We observed a doublet at 5.49 ppm integrating for one proton which corresponds to olefin proton. We also observed a doublet at 5.28 ppm integrating for one proton which corresponds to olefin proton. We obtained a singlet at 3.21 ppm integrating for two protons which corresponds to methylene. We also observed a singlet at 2.36 ppm integrating for three protons which corresponds to methyl group. We observed a broad singlet at 2.81 ppm integrating for one proton and exchangeable with D\(_2\)O and it corresponds to OH signal. In \(^{19}\)F NMR spectrum (Fig.5.3) of 2d, we observed a singlet at -79.20 ppm integrating for trifluoro methyl group. The \(^{13}\)C NMR spectrum (Fig.5.4) of 2d and Mass (Fig.5.5) of 2d spectral data suggest that compound 2d as a 1,1,1-trifluoro-4-phenyl-2-(trifluoromethyl)pent-4-en-2-ol. The compound 2d IR, \(^1\)H&\(^{13}\)C NMR and Mass spectral copies are presented at the end of this chapter.

Experimental

Typical experimental procedure for carbonyl-ene reaction with hexafluoroacetone trihydrate with alkenes under microwave heating:

\(\alpha\)-Methylstyrene (0.5 g, 4.2 mmol), hexafluoroacetone trihydrate (1.01 g, 4.6 mmol) and 3 Å molecular sieves (0.5 g, powder) were taken in a 10 ml pressure tube and subjected to microwave heating (CEM discover, 800 W, 100 °C, 16 psi) for 10 min. Next, the reaction mixture was diluted with dichloromethane (5 ml) and filtered. The molecular sieves were rinsed with dichloromethane (2x5 ml) and the combined extracts were concentrated and purified by normal column chromatography to obtain the corresponding addition product, 1,1,1-trifluoro-4-phenyl-2-(trifluoromethyl)pent-4-ene-2-ol 2a (1.38 g, 97%), in the form of colourless oil.
Typical experimental procedure for carbonyl-ene reaction with hexafluoroacetone trihydrate with alkenes under conventional heating:

α-Methylstyrene (0.5 g, 4.2 mmol), hexafluoroacetone trihydrate (1.01 g, 4.6 mmol) and 3 Å molecular sieves (0.5 g, powder) were taken in into a 25 ml round-bottomed flask fitted with a condenser and a calcium chloride guard tube. The mixture was heated on an oil bath at 100 °C for 24h and after completion of the reaction (tlc) it was extracted with dichloromethane following the procedure above. The extract was concentrated under reduced pressure. Purification of the crude by normal column chromatography afforded the corresponding addition product 2a (1.35 g) in 97% yield. The product obtained gave the following spectral data:

\[
\text{1,1,1-Trifluoro-4-phenyl-2-(trifluoromethyl)pent-4-en-2-ol (2a)}: \text{colourless oil}
\]

- IR (neat) : 3540, 3061, 1628, 1494, 1447, 1393, 1207, 1149, 1027, 988, 778, 669 cm\(^{-1}\).
- \(^1\)H NMR (CDCl\(_3\), 300 MHz) : δ 2.82 (1H, s, exchange with D\(_2\)O), 3.3 (2H, s), 5.38 (1H, s), 5.60 (1H, s), 7.31–7.63 (5H, m).
- \(^{13}\)C NMR (CDCl\(_3\), 75 MHz) : δ 35.6, 121.0, 125.2, 127.0, 129.0, 130, 140.9.
- \(^{19}\)F NMR (CDCl\(_3\), 300 MHz) : δ -77.25.
- EIMS (m/z) : 284 [M]+, 221, 197, 177, 147, 128, 103, 91.
4-(4-Chlorophenyl)-1,1,1-trifluoro-2-(trifluoromethyl)pent-4-en-2-ol (2b): colourless oil
IR (neat) : 3493, 3045, 1560, 1447, 1210, 1140, 1025, 775, 667 cm\(^{-1}\).
\(^1\)H NMR (CDCl\(_3\), 300 MHz) : \(\delta 7.38\) (m, 4H), 5.57 (s, 1H), 5.35 (s, 1H), 3.18 (s, 2H), 2.83 (s, 1H, exchange with D\(_2\)O).
\(^13\)C NMR (CDCl\(_3\), 75 MHz) : \(\delta 139.5, 138.2, 134.1, 129.0, 127.3, 123.5, 121.1, 120.0, 34.6\).
\(^19\)F NMR (CDCl\(_3\), 300 MHz) : \(\delta -76.81\).
EIMS (m/z) : 318 [M]\(^+\), 249, 151, 137, 69.

1,1,1-Trifluoro-4-(4-methoxyphenyl)-2-(trifluoromethyl)pent-4-en-2-ol (2c): colourless oil
IR (neat) : 3483, 2957, 1510, 1440, 1207, 1131, 1030, 798, 596 cm\(^{-1}\).
\(^1\)H NMR (CDCl\(_3\), 300 MHz) : \(\delta 7.35\) (d, \(J = 7.5\) Hz, 2H), 6.78 (d, \(J = 7.5\) Hz, 2H), 5.30 (d, \(J = 14.8\) Hz, 1H), 3.65 (bs, 1H, exchangeable with D\(_2\)O), 3.40 (s, 3H), 3.15 (s, 2H).
Studies on carbonyl-ene reactions of fluoroketones:

$^{13}$C NMR (CDCl$_3$, 75 MHz) : \( \delta 157.0, 139.6, 136.2, 129.1, 126.8, 123.3, 120.8, 119.5, 55.7, 32.0 \).

$^{19}$F NMR (CDCl$_3$, 300 MHz) : \( \delta -78.82 \).

EIMS (m/z) : 314 [M$^+$], 245, 181, 133, 69.

1,1,1-Trifluoro-4-(o-tolyl)-2-(trifluoromethyl)pent-4-en-2-ol (2d): colourless oil

IR (neat) : 3493, 3043, 1524, 1452, 1215, 1120, 1015, 786, 617 cm$^{-1}$.

$^1$H NMR (CDCl$_3$, 300 MHz) : \( \delta 7.19-7.24 (m, 4H), 5.49 (d, J = 14.0 \text{ Hz}, 1H), 5.27 (d, J =14.0 \text{ Hz}, 1H), 3.14 (s, 2H), 2.81 (bs, OH exchangeable with D$_2$O), 2.36 (s, 3H) \).

$^{13}$C NMR (CDCl$_3$, 75 MHz) : 140.3, 140.2, 135.1, 131.2, 128.3, 128.2, 126.3, 124.6, 122.8, 120.8, 36.5, 19.9.

$^{19}$F NMR (CDCl$_3$, 300 MHz) : \( \delta -79.20 \).

ESI-MS (m/z) : 299 [M+H$^+$], 229, 131, 117, 91, 69.

2-(Cyclohex-1-en-1-ylmethyl)-1,1,1,3,3,3-hexafluoropropan-2-ol (2e): colourless oil

IR (neat) : 3437, 2933, 1447, 1211, 1143, 1015 cm$^{-1}$.

$^1$H NMR (CDCl$_3$, 300 MHz) : \( \delta 5.73 (t, J = 13.7 \text{ Hz}, 1H), 3.15 (s, 1H, exchangeable with D$_2$O), 2.58 (s, 2H), 2.13 (m, 4H), 1.67 (m, 4H) \).
Studies on carbonyl-ene reactions of fluoroketones.....

\[^{13}\text{C}\] NMR (CDCl\(_3\), 75 MHz) : \(\delta\) 131.2, 128.0, 125.7, 121.5, 40.3, 29.9, 25.6, 23.0, 21.8.

\[^{19}\text{F}\] NMR (CDCl\(_3\), 300 MHz) : \(\delta\) -76.81.

EIMS (m/z) : 262 [M]\(^+\), 95, 81, 69, 55, 41.

2-((6, 6-Dimethylbicyclo[3.1.1]hept-2-en-2-yl)methyl)-1,1,1,3,3,3-hexafluoropropan-2-ol (2f) : yellow oil

IR (neat) : 3480, 2934, 1307, 1210, 1186, 1132, 1043, 992, 830, 709, 671 cm\(^{-1}\).

\[^{1}\text{H}\] NMR (CDCl\(_3\), 300 MHz) : \(\delta\) 5.35 (t, \(J = 12.8\) Hz, 1H), 2.21 (bs, 1H, exchangeable with D\(_2\)O), 1.98-1.67 (m, 6H), 1.58-1.42 (m, 2H), 1.21 (s, 3H), 1.19 (s, 3H).

\[^{13}\text{C}\] NMR (CDCl\(_3\), 75 MHz) : \(\delta\) 138.2, 122.7, 121.0, 118.5, 47.2, 43.4, 40.1, 32.3, 30.8, 25.5, 23.6.

\[^{19}\text{F}\] NMR (CDCl\(_3\), 300 MHz) : \(\delta\) -77.21.

ESI (m/z) : 302 [M]\(^+\), 233, 206, 166, 135, 96, 69.

1, 1, 1-Trifluoro-4-(4-methylcyclohex-3-en-1-yl)-2-(trifluoromethyl)pent-4-en-2-ol (2g) : yellow oil

IR (neat) : 3474, 3045, 1437, 1210, 1135, 911, 769, 654, 532 cm\(^{-1}\).
$^1$H NMR (CDCl$_3$, 300 MHz) : $\delta$ 5.37 (t, $J = 11.2$ Hz, 1H), 4.86 (d, $J = 7.5$ Hz, 1H), 4.70 (d, $J = 7.5$ Hz, 1H), 2.73 (d, $J = 8.9$ Hz, 1H), 2.69 (d, $J = 8.9$ Hz, 1H), 2.20 (m, 1H), 2.04 (bs, 1H, exchangeable with D$_2$O), 2.01 (m, 2H), 1.87 (m, 2H), 1.70 (s, 3H), 1.38 (m, 2H).

$^{13}$C NMR (CDCl$_3$, 75 MHz) : $\delta$ 154.6, 141.2, 133.0, 122.2, 110.2, 95.7, 42.0, 33.1, 32.0, 28.6, 23.8, 21.5.

$^{19}$F NMR (CDCl$_3$, 300 MHz) : $\delta$ -77.83.


1,1,1-Trifluoro-4, 5-dimethyl-2-(trifluoromethyl)hex-4-en-2-ol (2h): colourless oil

IR (neat) : 3453, 2994, 1207, 1157, 1020, 736, 632; 539 cm$^{-1}$.

$^1$H NMR (CDCl$_3$, 300 MHz) : $\delta$ 3.84 (s, 3H), 2.61 (s, 2H), 2.40 (bs, 1H, exchangeable with D$_2$O), 1.78 (s, 3H), 1.69 (s, 6H).

$^{13}$C NMR (CDCl$_3$, 75 MHz) : $\delta$ 141.3, 128.4, 122.1, 115.0, 23.0, 20.1, 18.2.

$^{19}$F NMR (CDCl$_3$, 300 MHz) : $\delta$ -76.91.

ESI (m/z) : 250 [M]$^+$, 181, 166, 83, 69.
Part B: Carbonyl-ene reactions of methyl 1,1,1-trifluoropyruvate

Introduction

The presence of a trifluoromethyl group in organic molecules often influences their chemical and biological properties due to a strong electron-withdrawing ability of the trifluoromethyl group.\(^8\) Hence, the development of the methodologies for the introducing of the trifluoromethylated building blocks is very important for the synthesis of many trifluoromethylated target molecules.

Ethyl or methyl ester of trifluoromethylpyruvic acid is an interesting compound from the pool of easily accessible and reactive building blocks for fluoroorganic synthesis.\(^8\) These compounds are extensively studied for their catalytic ene reactions with alkenes.\(^8\) However, due presence of strongly electron deficient carbonyl group, trifluoromethyl pyruvate has relatively low activation barrier to give thermal-induced non catalytic ene reaction with an alkene. Interestingly, such studies are scarcely known in literature.

In a recent report, Clarke et al.,\(^8\) have shown one example that ethyl 1,1,1-trifluoromethyl pyruvate undergoes non-catalytic ene reaction with 2-phenylpropene under microwave irradiation producing a mixture of 2- and 3-alkenols.

Present Work

We have recently found that methyl 1,1,1-trifluoropyruvate reacts in a way different from ethyl 1, 1, 1- pyruvate producing exclusively 3-alkenols in high yields as shown in Scheme 3.

![Scheme 3: Non-catalytic ene reaction of methyl 1,1,1-trifluoropyruvate with α–methyl styrene](image-url)
In this study, methyl 1,1,1-trifluoropyruvate has reacted efficiently with a variety of alkenes 3a-h giving exclusively the corresponding 3-alkenols 4a-h in high yields both under microwave irradiation (100 °C, 800 W, 10 min) and conventional heating (100 °C) conditions. These reactions have proceeded very rapidly (10 min) under microwave irradiation and very slowly under conventional heating (>16h) producing 3-alkenols 4a-h in 78-99% and 70-91% yields respectively. The representative results are shown in Table 3.

<table>
<thead>
<tr>
<th>Entry</th>
<th>Alkene (3)</th>
<th>Adduct (4)</th>
<th>Conventional heating</th>
<th>Microwave heating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>%Yield (time, h)</td>
<td>%Yield (time, min)</td>
</tr>
<tr>
<td>a</td>
<td><img src="image" alt="Alkene a" /></td>
<td><img src="image" alt="Adduct a" /></td>
<td>84(16)</td>
<td>96(10)</td>
</tr>
<tr>
<td>b</td>
<td><img src="image" alt="Alkene b" /></td>
<td><img src="image" alt="Adduct b" /></td>
<td>89(18)</td>
<td>98(10)</td>
</tr>
<tr>
<td>c</td>
<td><img src="image" alt="Alkene c" /></td>
<td><img src="image" alt="Adduct c" /></td>
<td>91(18)</td>
<td>94(10)</td>
</tr>
<tr>
<td>d</td>
<td><img src="image" alt="Alkene d" /></td>
<td><img src="image" alt="Adduct d" /></td>
<td>70(24)</td>
<td>78(10)</td>
</tr>
<tr>
<td>e</td>
<td><img src="image" alt="Alkene e" /></td>
<td><img src="image" alt="Adduct e" /></td>
<td>87(17)</td>
<td>99(10)</td>
</tr>
</tbody>
</table>
Studies on carbonyl-ene reactions of fluoroketones.

As an illustrative example, we characterized 4a based on its spectral data as follows: In IR spectrum (Fig.5.6) of 4a, we observed characteristic absorption bands at 3493 and 1746 cm\(^{-1}\), which corresponds to OH and COOMe functionalities respectively. In \(^1\)H NMR spectrum (Fig.5.7) of 4a, we observed a multiplet at 7.25 ppm integrating for five protons, which corresponds to aromatic protons. We observed a doublet at 5.38 ppm, \((J = 19.4\text{Hz})\) integrating for one proton which corresponds to olefin proton. We also observed a doublet at 5.25 ppm \((J = 19.4\text{Hz})\) integrating for one proton which corresponds to olefin proton. We observed a broad singlet at 3.72 ppm integrating for one proton and exchangeable with D\(_2\)O and it corresponds to OH signal. We obtained a singlet at 3.31 ppm, integrating for three protons which corresponds to methyl (-OCH\(_3\)). We obtained a doublet at 3.25 ppm, \((J = 13.2\text{Hz})\) integrating for one proton which corresponds to methylene. We also obtained a doublet at 3.01 ppm, \((J = 13.2\text{Hz})\) integrating for one proton which corresponds to methylene. In \(^1\)F NMR spectrum (Fig.5.8) of 4a, we observed a singlet at -64.89 ppm corresponds to CF\(_3\) group. The \(^{13}\)C NMR spectrum (Fig.5.9) of 4a and Mass (Fig.5.10) of 4a spectral data suggest that compound 4a as a methyl 2-hydroxy-4-phenyl-2-(trifluoromethyl) pent-4-enoate. The compound 4a IR, \(^1\)H&\(^{13}\)C NMR and Mass spectral copies are presented at the end of this chapter.

\(^{a}\)Isolated yields. All products were characterized by IR, \(^1\)H & \(^{13}\)C NMR and Mass spectral data
In summary, the present work describes a simple, efficient and economical method for the preparation of hexafluoroisopropanol functionalized and trifluoromethyl functionalized alcohol derivatives with high selectivity by a carbonyl-ene reaction of hexafluoroacetone trihydrate and trifluoromethyl pyruvate with alkenes having allylic hydrogens under microwave heating and also under conventional heating. This work is the first study on the carbonyl-ene reactions of hydrated hexafluoroacetone using simple solid catalysts, which are inexpensive, easily recoverable and recyclable.

**Experimental**

**Typical method for preparation of 3-alkenol by non-catalytic ene reaction of methyl 1,1,1-trifluoropyruvate with an alkene under microwave heating:**

2-phenylpropene $3a$ (1.0 g, 8.4 mmol) and methyl 1,1,1-trifluoropyruvate (1.28 g, 8.4 mmol) were taken in a pressure tube and subjected to microwave irradiation (CEN discover, 800 W, 100 °C, 16 psi, 10 min.). The reaction mixture was diluted with dichloromethane (5 ml) were concentrated and purified by normal column chromatography (silica gel 60-120mesh, hexane and ethyl acetate 9:1) to obtain the corresponding addition product, methyl 2-hydroxy-4-phenyl-2-(trifluoromethyl) pent-4-enoate $4a$ (2.26 g, 96%) in the form of pale yellow oil.

**Procedure for reaction under conventional heating:** The reaction mixture was taken as above into a 25 ml round bottomed flask fitted with a condenser and a calcium chloride guard tube. The mixture was heated on an oil bath at 100 °C for 16 h and after completion of the reaction (tlc), it was diluted with dichloromethane were concentrated under reduced pressure. Purification of the crude by normal column Chromatography afforded the corresponding addition product (1.94 g) in 84% yield. The product obtained gave the following spectral data:
Methyl 2-hydroxy-4-phenyl-2-(trifluoromethyl) pent-4-enoate (4a): pale yellow oil.

IR (neat): 3493, 3028, 2957, 1746, 1629, 1493, 1445, 1314, 1231, 1186, 1136, 702 cm$^{-1}$.

$^1$H NMR (CDCl$_3$, 300 MHz): $\delta$ 7.25-7.30 (m, 5H), 5.38 (d, $J$ = 19.4 Hz, 1H), 5.25 (d, $J$ = 19 Hz, 1H), 3.72 (bs, 1H, exchangeable with D$_2$O), 3.31 (s, 3H), 3.25 (d, $J$ = 13.2 Hz, 1H), 3.01 (d, $J$ = 13.2 Hz, 1H).

$^{13}$C NMR (CDCl$_3$, 75 MHz): 168.0, 142.5, 40.0, 129.5, 128.4, 127.0, 125.0, 122.0, 118.2, 52.5, 37.5.

$^{19}$F NMR (CDCl$_3$, 300 MHz): $\delta$ -64.89.

EIMS (m/z): 274 (M$^+$), 256, 241, 225, 197, 177, 145, 115, 103, 91, 77.

HRMS (ESI): C$_{13}$H$_{13}$O$_3$F$_3$Na: 297.0714 (calcd: 297.0705).

Methyl-2-hydroxy 4-(4-chlorophenyl)-2-(trifluoromethyl)pent-4-enoate (4b):

Pale yellow oil

IR (neat): 3440, 2958, 2925, 2854, 1757, 1634, 1493, 1448, 1367, 1221, 1182, 1102, 1035, 933, 648 cm$^{-1}$.
Methyl-2-hydroxy 4-(4-methoxyphenyl)-2-(trifluoromethyl) pent-4-enoate (4c):

Yellow oil

IR (neat) : 3488, 2958, 2842, 1746, 1607, 1513, 1444, 1309, 1230, 1182, 1099, 955, 837, 650 cm⁻¹.

\(^1\)H NMR (CDCl₃, 300 MHz) : \(\delta 7.37 (d, J = 8.7 \text{ Hz}, 2H), 6.84 (d, J = 8.7 \text{ Hz}, 2H), 5.31 (d, J = 14.2 \text{ Hz}, 1H), 5.20 (d, J = 14.2 \text{ Hz}, 1H), 3.83 (s, 3H), 3.65 (bs, 1H, exchangeable with D₂O), 3.40 (s, 3H), 3.27 (d, J = 13.7 Hz, 1H), 2.95 (d, J = 13.7 Hz, 1H).

\(^1\)C NMR (CDCl₃, 75 MHz) : \(\delta 169.4, 159.6, 150.3, 141.0, 132.0, 128.3, 114.5, 112.0, 90.0, 63.7, 52.0, 24.6.

\(^1\)F NMR (CDCl₃, 300 MHz) : \(\delta -69.62.

ESI (m/z) : 305 [M+H]^+

HRESI-MS : C\(_{14}\)H\(_{15}\)F\(_3\)O\(_4\)Na: 327.0918 (calcd: 327.0912).
Methyl-2-hydroxy 4-(4-methylphenyl)-2-(trifluoromethyl)pent-4-enoate (4d):

Pale yellow oil

IR (neat) : 3468, 2946, 2847, 1738, 1607, 1483, 1432, 1306, 1226, 1182, 945, 825, 659 cm⁻¹.

¹H NMR (CDCl₃, 300 MHz) : δ 7.35 (d, J = 8.4 Hz, 2H), 6.72 (d, J = 8.4 Hz, 2H), 5.2 (d, J = 14.2 Hz, 1H), 5.13 (d, J = 14.2 Hz, 1H), 3.84 (s, 3H), 3.40 (bs, 1H, exchangeable with D₂O), 3.27 (d, J = 13.5 Hz, 1H), 2.95 (d, J = 13.5 Hz, 1H), 2.43 (s, 3H).

¹³C NMR (CDCl₃, 75 MHz) : δ 168.6, 150.0, 143.0, 135.0, 129.0, 127.4, 112.0, 90.7, 53.7, 39.2, 25.0.

¹⁹F NMR (CDCl₃, 300 MHz) : δ -67.83.

ESI (m/z) : 289 [M+H]⁺

HRESI-MS : C₁₄H₁₅F₃O₃Na: 311.0857 (calcld: 311.0848).

Methyl 2-(cyclohexenylmethyl)-3,3,3-trifluoro-2-hydroxypropanoate (4e):

Colourless oil

IR (neat) : 3437, 2933, 2861, 1748, 1447, 1211, 1143, 1083, 1026, 906, 761, 664 cm⁻¹.

¹H NMR (CDCl₃, 300 MHz) : δ 5.52 (t, J = 10.2 Hz, 1H), 3.9 (s, 3H), 3.70 (bs, 1H, exchangeable with D₂O), 2.64 (d, J =
Chapter 5

Studies on carbonyl-ene reactions of fluoroketones....

\[
\begin{align*}
\text{Methyl 2-((6,6-dimethylbicyclo}[3.1.1]\text{hept-2-en-2-yl})methyl)-3,3,3-\text{trifluoro-2-}
\text{Hydroxypropanoate (4f)}: & \quad \text{Yellow oil} \\
\text{IR (neat)} & : \quad 3503, 2917, 2635, 1746, 1442, 1366, 1307, \\
& \quad 1228, 1186, 1132, 1043, 992, 888, 830, 709, \\
& \quad 671 \text{ cm}^{-1}. \\
\text{\textsuperscript{1}H NMR (CDCl\textsubscript{3}, 300 MHz)} & : \quad \delta 5.41 (t, J = 14.6 \text{ Hz}, 1\text{H}), 3.90 (s, 3\text{H}), 3.74 \\
& \quad (d, J = 18.6 \text{ Hz}, 1\text{H}), 2.80 (d, J = 18.6 \text{ Hz}, 1\text{H}), \\
& \quad 2.37 (m, 4\text{H}), 2.26 (bs, 1\text{H}, \text{exchangeable with} \\
& \quad \text{D}_{2}\text{O}), 2.15 (m, 1\text{H}), 1.34 (s, 3\text{H}), 1.05 (t, J \\
& \quad = 14.6 \text{ Hz}, 1\text{H}), 0.83 (s, 3\text{H}). \\
\text{\textsuperscript{13}C NMR (CDCl\textsubscript{3}, 75 MHz)} & : \quad \delta 169.0, 142.7, 138.2, 121.0, 92.5, 54.0, 46.4, \\
& \quad 43.2, 41.0, 32.6, 31.0, 25.8, 23.0. \\
\text{\textsuperscript{19}F NMR (CDCl\textsubscript{3}, 300 MHz)} & : \quad \delta -68.03. \\
\text{ESI (m/z)} & : \quad 293 \text{ [M+H]}^{+} \\
\text{HRESI-MS} & : \quad \text{C}_{14}\text{H}_{20}\text{F}_{3}\text{O}_{3}: 293.1184 \text{ (calcd: 293.1175)}. \\
\end{align*}
\]
Methyl 2-hydroxy-4-(4-methylcyclohex-3-enyl)-2-(trifluoromethyl)pent-4-enoate (4g):

Yellow oil

IR (neat) : 3488, 2924, 1745, 1640, 1445, 1214, 1144, 998, 911, 799, 674, 532 cm\(^{-1}\).

\(^1\)H NMR (CDCl\(_3\), 300 MHz) : \(\delta \) 5.35 (t, \(J = 10.4\) Hz, 1H), 4.92 (d, \(J = 8.9\) Hz, 1H), 4.85 (d, \(J = 8.9\) Hz, 1H), 3.80 (s, 3H), 2.87 (d, \(J = 9.4\) Hz, 1H), 2.71 (d, \(J = 9.4\) Hz, 1H), 2.25 (m, 1H), 2.12 (m, 2H), 2.07 (bs, 1H, exchangeable with D\(_2\)O), 1.90 (m, 2H), 1.75 (s, 3H), 1.42 (m, 2H).

\(^13\)C NMR (CDCl\(_3\), 75 MHz) : \(\delta \) 168.0, 155.8, 142.0, 135.0, 122.4, 107.0, 90.2, 53.7, 41.8, 32.0, 28.6, 23.5, 22.0.

\(^19\)F NMR (CDCl\(_3\), 300 MHz) : \(\delta \) -67.25.

ESI (m/z) : 293 [M+H]\(^+\)

HRESI-MS : C\(_{14}\)H\(_{19}\)F\(_3\)O\(_3\)Na: 315.0874 (calcd: 315.0858).

Methyl 2-hydroxy-4, 5-dimethyl-2-(trifluoromethyl)hex-4-enoate (4h): colourless oil

IR (neat) : 3466, 2938, 2827, 1745, 1624, 1246, 1172, 1056, 929, 845, 737, 624; 540 cm\(^{-1}\).

\(^1\)H NMR (CDCl\(_3\), 300 MHz) : \(\delta \) 3.84 (s, 3H), 3.53 (bs, 1H, exchangeable with D\(_2\)O), 2.61 (d, \(J = 14.7\) Hz, 1H), 2.43 (d, \(J = 14.7\) Hz, 1H), 1.75 (s, 3H), 1.73 (s, 6H).

141
<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>$^{13}$C NMR (CDCl$_3$, 75 MHz)</strong></td>
<td>$\delta$ 167.8, 143.0, 128.6, 125.3, 93.5, 54.0, 23.5, 19.7, 18.0.</td>
<td></td>
</tr>
<tr>
<td><strong>$^{19}$F NMR (CDCl$_3$, 300 MHz)</strong></td>
<td>$\delta$ -70.01.</td>
<td></td>
</tr>
<tr>
<td><strong>ESI (m/z)</strong></td>
<td>241 [M+H]$^+$</td>
<td></td>
</tr>
<tr>
<td><strong>HRESI-MS</strong></td>
<td>C$<em>{10}$H$</em>{15}$F$_3$O$_3$Na: 263.0874 (calcd: 263.0867).</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 5.1. IR Spectrum of 1,1,1-trifluoro-4-(o-tolyl)-2-(trifluoromethyl)pent-4-en-2-ol (2d)
Fig. 5. 1H NMR Spectrum of 1,1,1-trifluoro-4-(o-tolyl)-2-(trifluoromethyl)pent-4-en-2-ol (2d)
Fig. 5. 3. $^{13}$C NMR Spectrum of 1,1,1-trifluoro-4-(o-tolyl)-2-(trifluoromethyl)pent-4-en-2-ol (2d)
Fig. 5. 19F NMR Spectrum of 1,1,1-trifluoro-4-(o-tolyl)-2-(trifluoromethyl)pent-4-en-2-ol (2d)
Fig. 5. ESI-MASS Spectrum of 1,1,1-trifluoro-4-(o-tolyl)-2-(trifluoromethyl)pent-4-en-2-ol (2d)
Fig. 5.6. IR Spectrum of methyl 2-hydroxy-4-phenyl-2-(trifluoromethyl)pent-4-enoate (4a)
Fig. 5.7. $^1$H NMR spectrum of methyl 2-hydroxy-4-phenyl-2-(trifluoromethyl)pent-4-enoate (4a)
Fig. 5.8. $^{13}$C NMR spectrum of methyl 2-hydroxy-4-phenyl-2-(trifluoromethyl)pent-4-enoate (4a)
Fig. 5.9. $^{19}$F NMR spectrum of methyl 2-hydroxy-4-phenyl-2-(trifluoromethyl)pent-4-enoate (4a)
Fig. 5.10. HRMS spectrum of methyl 2-hydroxy-4-phenyl-2-(trifluoromethyl)pent-4-enoate (4a)